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OPTICAL ANALYSIS OF A MULTICOLOR MODEL OF THE 360 DEGREE NONPRO--ETC(U)
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TECHNICAL REPORT: NAVTRAEQUIPCEN IH-282

OPTICAL ANALYSIS OF A MULTICOLOR MODEL OF THE 360 DEGREE NONPROGRAMMED VISUAL DISPLAY

Physical Sciences Laboratory
Naval Training Equipment Center
Orlando, Florida 32813

April 1977

Interim Report

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NAVAL TRAINING EQUIPMENT CENTER
ORLANDO, FLORIDA 32813

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OPTICAL ANALYSIS OF A MULTICOLOR MODEL OF THE 360 DEGREE NONPROGRAMMED VISUAL DISPLAY

NEIL MOHON
Physical Sciences Laboratory

April 1977

Approved:

GEORGE DERDERIAN
Head, Physical Sciences Laboratory

JAMES F. HARVEY
Director
Research and Technology Department

(The findings in this report are not to be construed as an official Dept. of the Army position unless so designated by other authorized documents.)

NAVAL TRAINING EQUIPMENT CENTER

ORLANDO, FLORIDA 32813

PREFACE

Task No. 7719 is now underway in the Research and Technology Department of NAVTRAEQUIPCEN to develop a feasibility demonstration model of a single color 360^o Non-Programmed Visual Display. The system has two major subsystems: a model board which is viewed by a probe, and a projector which produces a real time display.

The model board probe is composed in part of a novel catadioptric annular lens which continuously views a $360^o \times 60^o$ scene on the model board, a rotating prism which spins the $360^o \times 60^o$ scene information across an annular detector array, and 12 radially positioned charge coupled devices which serve as the detector array.

The projector is composed in part of a multi-faceted, rotating, mirror scanner which projects 12 independently modulated lasers beams onto a $360^o \times 60^o$ screen in real time relative to the scene viewed by the model board probe, a de-rotation prism to frame lock the image scene to the screen, and a second type of catadioptric, annular lens to correctly image the information bearing laser beams onto the screen.

This task has been funded by the Naval Air Systems Command and the US Army Project Manager for Training Devices.

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A preliminary optical analysis is presented of the various problems involved in converting a monochromatic 360 degree nonprogrammed visual display to multicolor. It discusses the lens design, selection of the number and wavelength of appropriate lasers, color separation filters, the spectral response of CCDs, color flicker and frame rate, and color laser speckle. Much technical planning and design is required; but no insurmountable technical difficulties are foreseen.

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SECTION I

INTRODUCTION

This report presents a preliminary optical analysis of the technical difficulties involved in adding multicolor to the 360 Degree Nonprogrammed Trainer (TNT) which is presently being developed as a monochromatic display by the Physical Sciences Laboratory of the Naval Training Equipment Center (NAVTRAEQUIPCEN). The TNT has two major components: A model board with optical probe, and a 360° x 60° projected display utilizing 12 lasers.

The optical probe is designed to constantly receive a 360° x 60° view over the model board and image the scene onto an annular image plane. The image is rotated by a prism across 12 charged coupled devices (CCD) which read and digitize the constantly changing image.

The projected display is composed of 12 scanned laser beams, which are modulated by information received from the CCD's in the model board probe, and projected onto a 3.05 meter radius spherical screen. The screen is composed of 12 30° x 60° sectors each which is vertically scanned sequentially by one laser beam at a time. Argon lasers (514 nm) are being used in the monochromatic model of TNT. Each of the 12 30° sectors will be scanned twice during each 1/30th of a second frame by the 12 lasers. The first scan will produce 300 vertical lines on one sector in the first 1/60th of a second. The second scan will produce another 300 lines on the same sector in the second 1/60th of a second and will interlace with the first 300 lines.

There are at least six major areas that need careful attention in converting to a multicolor system:

a. Lens Design

b. Laser light proportion

c. Color separation filters

d. CCD spectral response

e. Flicker/frame rate

f. Laser speckle

SECTION II

LENS DESIGN

The lens designer for the projector and probe has included correction for primary and secondary color; therefore, it should perform properly in a multicolor model of the TNT without chromatic aberration. The designer has omitted cemented elements in the projector design in order to avoid complicating any heating problem that might exist. Some of the projector lens elements were made of calcium fluoride; and there was concern as to whether this material had sufficient thermal shock characteristics to be usable. The glass manufacturer and the contractor who is to build the lens both performed theoretical thermal calculations on the calcium fluoride and determined it was satisfactory, primarily because the laser energy is concentrated in a narrow band in the visible spectrum having no infrared components. Experiments were performed in-house to verify the thermal characteristics by passing an argon laser beam of 200 w/cm^2 through a 1 cm thick blank of calcium fluoride in controlled tests. No deterioration was observed in the blank. It is concluded from the calculations and experiments that heating from high-power color lasers should offer no problem. However, infrared lasers should be avoided because of the calcium fluoride elements in the design.

SECTION III

LASER LIGHT PROPORTIONS[1,2]

Proper proportions of the various available laser lines can be mixed to produce white light or other colored lights to yield realistic color in TNT. This may be accomplished using either three or four colored laser lines.

THREE COLOR SYSTEM

A survey was performed of all commercial laser systems to determine which spectrum lines were available having the powers required for the TNT. (All of these systems were comparable in price and specified reliability, so no selection was made based on these two factors.) It was desirable to find lines as near as possible to 400 nm, 515 nm, and 700 nm, in order that the system would be capable of producing most colors.

The available predominant laser lines and their tristimulus values are given in table 1.

TABLE 1. LASER LINES AND TRISTIMULUS VALUES

λ	$\bar{x}$	$\bar{y}$	$\bar{z}$
488 nm	.0424	.1925	.5256
514 nm	.0251	.5872	.1210
647 nm	.3299	.1257	0

The tristimulus value of the sum of the three lines is found by,

$$X = \bar{x}_b\phi_b + \bar{x}_g\phi_g + \bar{x}_r\phi_r$$

$$Y = \bar{y}_b\phi_b + \bar{y}_g\phi_g + \bar{y}_r\phi_r$$

$$Z = \bar{z}_b\phi_b + \bar{z}_g\phi_g + \bar{z}_r\phi_r$$

1. L. A. Jones, et. al., The Science of Color, Optical Society of America, Washington, 1970, Pg 236-253.
2. Deane Judd, "Colorimetry," Circular of the National Bureau of Standards, Pg. 473-504.

where ϕ is the radiant power in the various lines. And the chromaticity coordinates of the sum of all the laser lines are,

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

therefore, let us fix x and y both equal to .3333 (i.e. white) and determine what are the required ratios of ϕ_b, ϕ_g, and ϕ_r to yield white light.

Hence, for x,

$$.3333 = \frac{.0424\ \phi_b + .0251\ \phi_g + .3299\ \phi_r}{.7605\ \phi_b + .7333\ \phi_g + .4556\ \phi_r}$$

and for y,

$$.3333 = \frac{.1925\ \phi_b + .5872\ \phi_g + .1257\ \phi_r}{.7605\ \phi_b + .7333\ \phi_g + .4556\ \phi_r}.$$

Upon solving these equations we find the ratios required are,

$$\phi_r = 5.231\ \phi_g$$

$$\phi_b = 3.373\ \phi_g.$$

The total radiant power required for a 10 foot-lambert luminance on a diffuse screen can be determined by totalling the products of the $\bar{y}$ tristimulus values for each laser line times the irradiance in that line and multiplying by the luminous efficiency, i.e.,

$$(.1925\ E_b + .5872\ E_g + .1257\ E_r)(680\ \frac{\text{lumens}}{\text{watt}}) = 10\ \frac{\text{lumen}}{\text{ft}^2}$$

or,

$$[(.1925)(3.373\ E_g)+(.5872\ E_g)+(1.257)(5.231\ E_g)][680\ \frac{1}{w}] = 10\ \frac{1}{\text{ft}^2}$$

$$E_g = 0.008143\ \text{w/ft}^2.$$

The area of the screen is,

$$A = 2\ \pi\ r\ h = 2\ \pi\ (10\ \text{ft})(11.54\ \text{ft})$$

$$= 725\ \text{ft}^2.$$

Thus the required radiant powers are,

$$\phi_g = A\ E_g$$

$$= (725\ ft^2)(.008143\ \frac{W}{ft^2})$$

$$\phi_g = 5.90\ W.$$

and similiarly,

$$\phi_b = 19.9\ W$$

$$\phi_r = 30.86\ W$$

If the screen has a gain of 8, then the radiant powers required are reduced to,

$$\phi_g = 0.74\ W$$

$$\phi_b = 2.49\ W$$

$$\phi_r = 3.86\ W$$

Assuming the throughput of the entire lens and optical system to be 10%, then the total radiant power at the lasers must be,

ϕ_g = 7.4 W green

ϕ_b = 24.9 W blue

ϕ_r = 38.6 W red

Assuming that each total radiant power is produced by four lasers, then we require,

four 1.85 watt argon lasers at 514 nm

four 6.23 watt argon lasers at 488 nm

four 9.65 watt krypton lasers at 647 nm

Using commercially available lasers, we can attain only,

1.85 watts at 514 nm (green)

6 watts at 488 nm (blue)

6 watts at 647 nm (red)

Then using this data we recalculate the whiteness. First we find,

$$X = (.0424)(24) + (.0251)(7.4) + (.3299)(24) = 9.121$$

$$Y = (.1925)(24) + (.5872)(7.4) + (.1257)(24) = 11.982$$

$$Z = (.5256)(24) + (.1210)(7.4) + 0 = 13.510$$

Then,

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$\boxed{\begin{aligned} x &= .2635 \\ y &= .3462 \end{aligned}}$$

This color is white with a slightly bluish green tint. It would probably be satisfactory.

The luminance of the screen is found by,

$$E = (y_b \phi_b + y_g \phi_g + y_r \phi_r)(K)\left(\frac{1}{\text{area}}\right)(\text{Throughput})$$

$$= [(.1925)(24)+(.5872)(7.4)+(.1257)(24)][680]\left[\frac{1}{725}\right]\left[\frac{1}{10}\right]$$

$$= 1.124 \text{ lumen/ft}^2.$$

Assuming a screen gain of 8, this yields

$$\boxed{9 \text{ foot-lamberts}}$$

The colors that may be achieved with this three color combination are shown inside the triangle on figure 1. It would be difficult to achieve pure blues and purples; but all other colors would appear realistic.

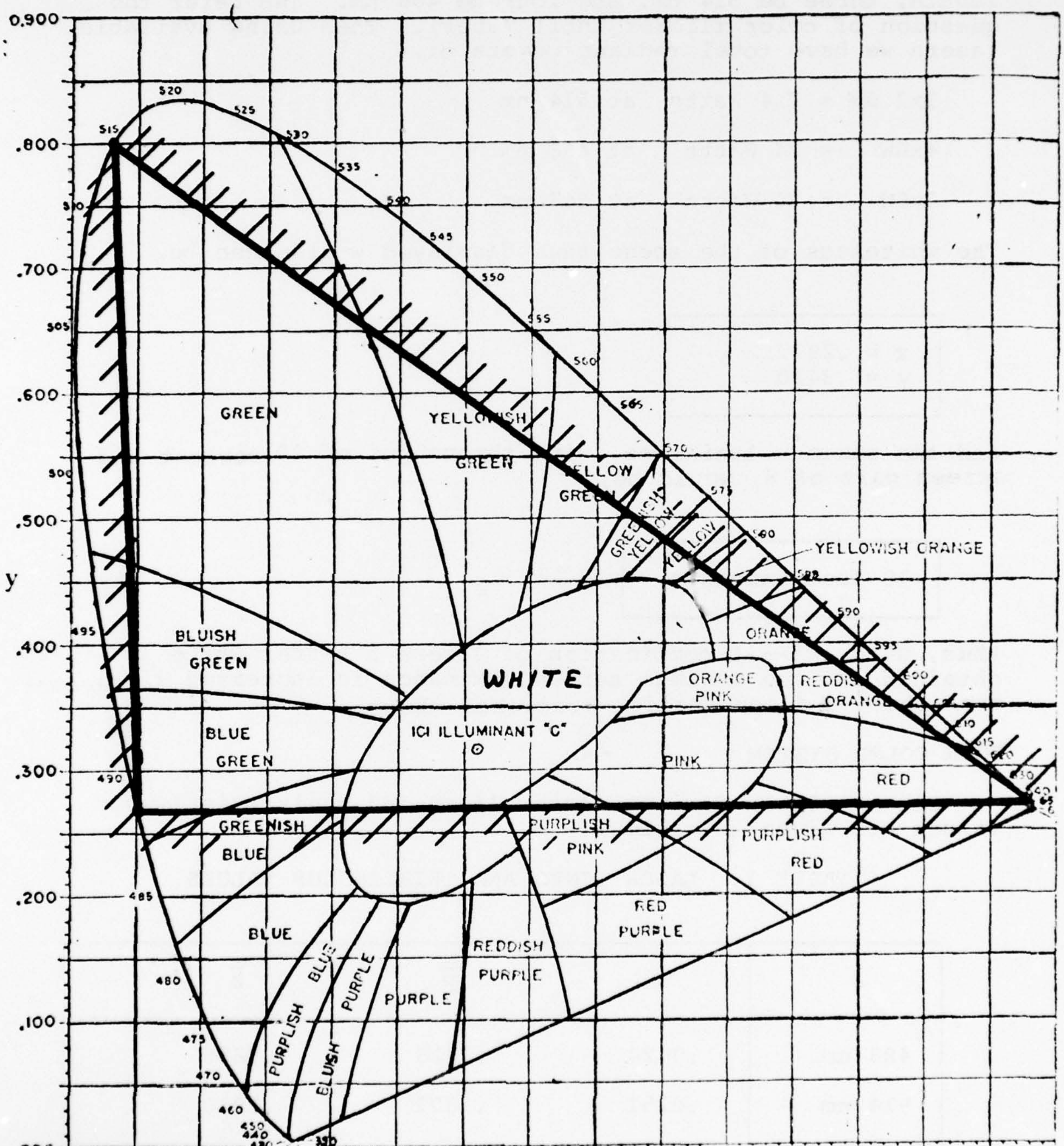

Figure 1. Colors Produced by Three Laser Colors

Suppose we let five of the 12 lasers be 647 nm in wavelength, three be 514 nm, and four be 488 nm. [We defer the question of color flicker until later]. Then using available lasers we have total radiant powers of,

3x2.5W = 7.4 Watts at 514 nm

4x6W = 24 Watts at 488 nm

5x6W = 30 Watts at 647 nm.

The whiteness of the scene thus displayed would then be,

$$\boxed{\begin{aligned} x &= .2972 \\ y &= .3410 \end{aligned}}$$

and the maximum luminance, with throughput of 10 percent and screen gain of 8, would be,

$$\boxed{\text{10 foot-lamberts}}$$

thus, with a 5-3-4 combination of lasers a better white is obtained and the maximum screen luminance is increased 11 percent over the 4-4-4 combination described above.

FOUR COLOR SYSTEM

The available dominant laser lines and their tristimulus values are given in table 2.

TABLE 2. LASER LINES AND TRISTIMULUS VALUES

λ	$\bar{x}$	$\bar{y}$	$\bar{z}$
488 nm	.0424	.1925	.5256
514 nm	.0251	.5872	.1210
568 nm	.7286	.9626	.0023
647 nm	.3299	.1257	0

The tristimulus values of the sum are,

$$X = \bar{x}_b\phi_b + \bar{x}_g\phi_g + \bar{x}_y\phi_y + \bar{x}_r\phi_r$$

$$Y = \bar{y}_b\phi_b + \bar{y}_g\phi_g + \bar{y}_y\phi_y + \bar{y}_r\phi_r$$

$$Z = \bar{z}_b\phi_b + \bar{z}_g\phi_g + \bar{z}_y\phi_y + \bar{z}_r\phi_r$$

Substituting in known values, requiring that the sum be located at x = .3333 and y = .3333 for whiteness, and solving we find,

$$\phi_y = -1.158\ \phi_g + 0.2212\ \phi_r$$

$$\phi_b = -1.939\ \phi_g + 1.0152\ \phi_r$$

Selecting available laser values and solving, we find that one solution is,

$$E_r = .0300\ \text{w/ft}^2$$

$$E_y = .0049\ \text{w/ft}^2$$

$$E_g = .0015\ \text{w/ft}^2$$

$$E_b = .0275\ \text{w/ft}^2$$

With a screen area of 725 ft^2, gain of 8, and optical throughput of 10 percent, this yields,

$$\phi_r = 27.2\ \text{Watt}$$

$$\phi_y = 4.50\ \text{Watt}$$

$$\phi_g = 1.36\ \text{Watt}$$

$$\phi_b = 24.9\ \text{Watt}$$

Assuming each total radiant power is the result of three lasers, then the following lasers are required:

three 9.1 watt krypton lasers at 647 nm

three 1.5 watt krypton lasers at 568 nm

three 0.45 watt argon lasers at 514 nm

three 8.3 watt argon lasers at 488 nm

However, at this time we have available only 6 watts at 647 nm, 0.9 watts at 568 nm, and 6 watts at 488 nm. Using this data, we recalculate the whiteness and find the chromaticity coordinates to be,

$$\boxed{\begin{aligned} x &= 0.3170 \\ y &= 0.3322 \end{aligned}}$$

which is a very good white. The maximum luminance of the screen, assuming a throughput of 10 percent and screen gain of 8, will be

$$\boxed{7 \text{ foot-lamberts}}$$

The colors that are possible with this combination of laser lines are shown inside the quadrangle on figure 2. The colors are essentially the same as are available with the three color lasers described above; but the screen luminance is substantially lower. We have diluted our red and blue reservoir by including the yellow laser lines.

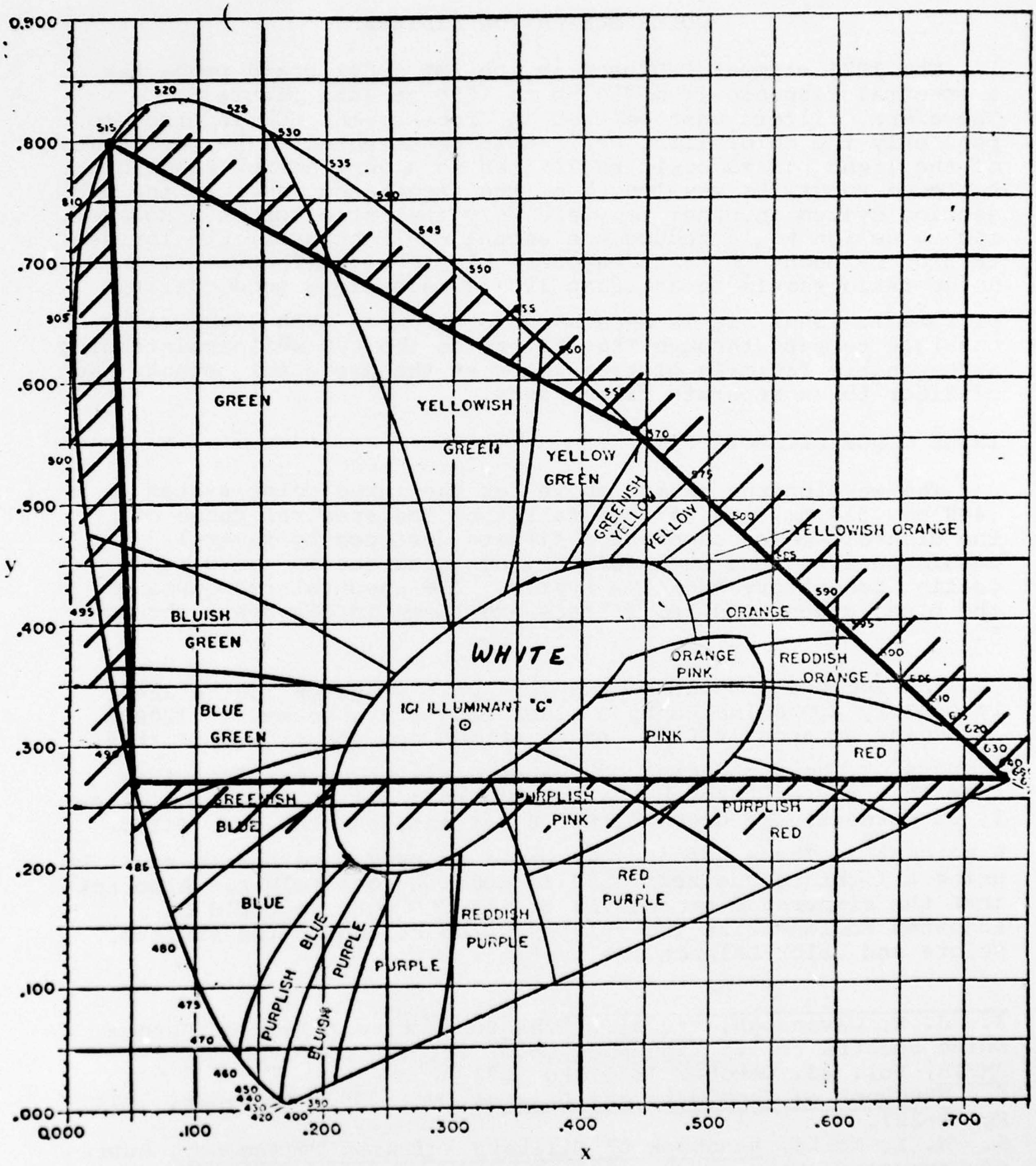

Figure 2. Colors Available with Four Laser Colors

SECTION IV

COLOR SEPARATION FILTERS

The 1024 element CCD used in the TNT model board probe has a spectral response from 450 nm to 1050 nm (see figure 6). Therefore, filters must be used in front of the CCD in order to pass only the color light desired to be detected. The wavelength of the light passed could be limited to a very narrow bandwidth centered about the wavelength of the associated laser in the projection system in order to yield very realistic colors. However, such a design would reduce the amount of light available for detection by each CCD to an unacceptable level. (The signal-to-noise ratio should be at least 100 to maintain a good quality picture[3]). Thus, it is necessary to allow as much light as possible to pass through the filters to the CCD while maintaining a reasonable facimile of true color at the projector output. We consider three separate filter sets.

THREE COLOR DICHROIC SET

The wavelengths chosen above for the three color system (488 nm, 514 nm, and 647 nm) fall into the spectral range of the dichroic color separation filters designed by several manufacturers. One such suitably designed set is the Optical Coating Laboratory Additive System. The spectral responses of the blue, green, and red filters are shown in figures 3 through 5.

The spectral output of the 1000 Watt Tungsten Iodine lamp is closely approximated by a black body curve peaked at 3200°K. It begins at about 400 nm, peaks at 900 nm, and tails off to 6 microns[4]. The percentage of the total light output from this lamp that passes through the red dichroic filter is approximately 22 percent, the green filter 8 percent, and the blue filter 6 percent[5]. These percentages could be made more nearly equal by using a light source near 5500 to 6000 degrees Kelvin. Also note that the electronic processing of the CCD outputs could be adjusted to linearize the relative proportions of the various colors and color balance the system.

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3. J. R. Cavanaugh, et. al., "The Subjective Effect of Random Noise Spectra on 525 Line NTSC Color Television," Journal SMPTE, Vol. 83, October 1974, Pg. 832.
4. Handbook of Chemistry and Physics, Vol. 55, CRC Press, 1974, Pg. E-227.
5. W. L. Wolfe, Handbook of Military Infrared Technology, Supt. of Documents, Washington, 1965, Pg. 18-19.

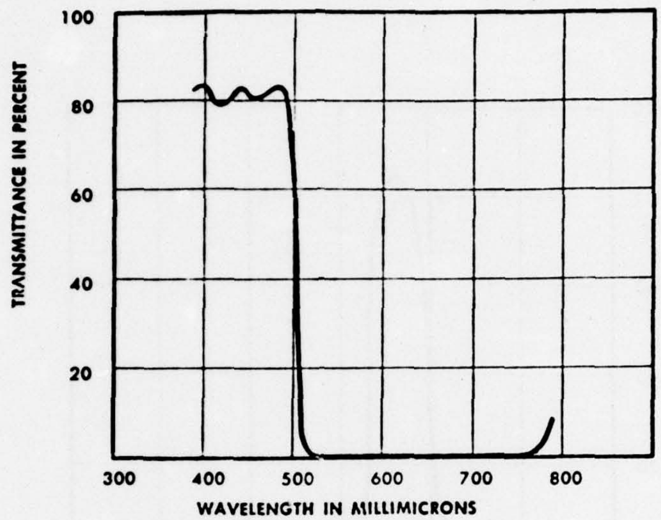

Figure 3. Blue Dichroic Filter

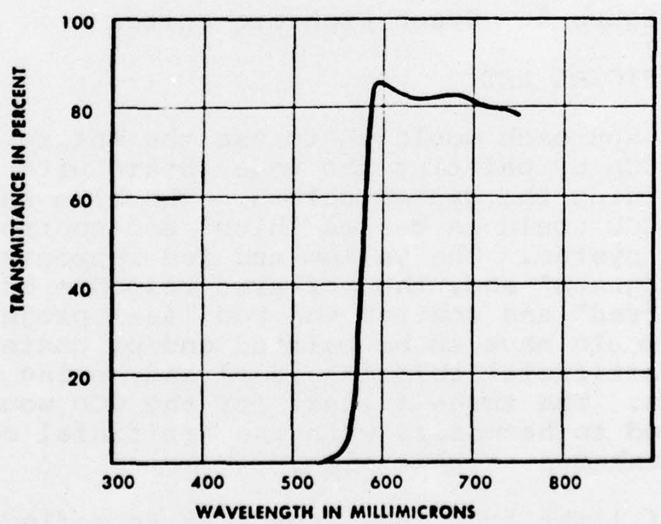

Figure 4. Red Dichroic Filter

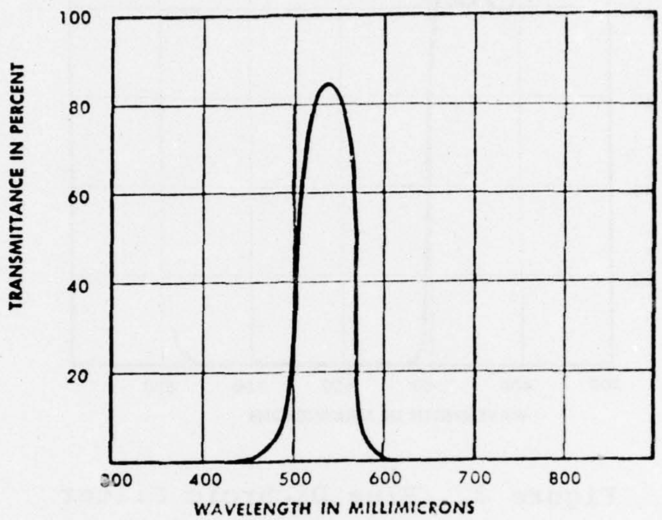

Figure 5. Green Dichroic Filter

THREE COLOR ARTIFICIAL SET

An alternate approach would be to use the entire spectral response of the CCD by painting the model board with artificial colors and redefining the system colors. The blue and green response of the CCD could be called "blue" and control the blue laser projection system. The yellow and red response of the CCD could be called "green" and, the infrared response of the CCD could be called "red" and control the red laser projection system. The model board would have to be painted and/or coated appropriately; but such artificial coloring is already being done for FLIR model boards. The three filters for the CCD would have to be special ordered to harmonize with the artificial color scheme and the cost is unknown at this time.

The amount of light from the lamps that is reflected by the model board (with r = 0.45) and passed through the artificial red filter is 12 percent, the artificial green filter 12 percent, and the artificial blue filter 12 percent. This scheme not only linearizes the data, but actually presents more detectable light to the CCD's. (See Section V).

FOUR COLOR SET

The four wavelengths listed in Table 2 (488 nm, 514 nm, 568 nm, and 647 nm) were used to select bandpass filters for discriminating the light approaching the CCD from the model board. One suitable set of filters is manufactured by Baird Atomic and is shown in table 3.

TABLE 3. SELECTED FOUR COLOR FILTERS

Catalog No.	Peak Wavelength	Transmission	Bandwidth
24-49-1	488 nm	50-80%	88 nm
24-69-9	514	60-80%	103
Special Order	568	50-80%	100
25-70-6	647	60-80%	116

The narrow bandwidth of these filters will significantly reduce the amount of light available to the CCD units and throw away most of the light from the 3200°K model board lamps. Such a four color system may however yield more realistic color than the three color scheme.

The amount of light from the lamps that is reflected by the model board (r = 0.45) and passed by the red filter is 4 percent, yellow filter 4 percent, green filter 7 percent, and blue filter 4 percent. This scheme linearizes the system reasonably well; but about half of the available light is lost and undetectable by the CCD's.

SECTION V

CHARGE COUPLED DEVICE SPECTRAL RESPONSE

The spectral response of the Fairchild 1024 element charge coupled device (CCD) selected for the monochromatic TNT is not a linear function of wavelength. The typical response, as well as the average range of response, is shown in figure 6.

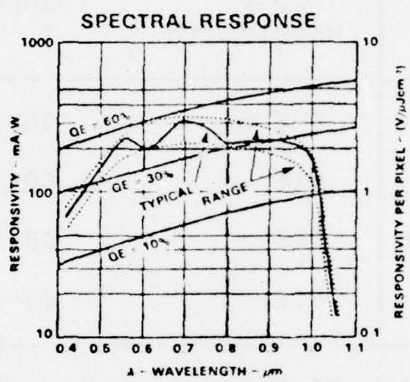

Figure 6. Spectral Response of 1024 Element CCD[6]

The percentage of the light, reflected from the model board and passed by the various filter combinations, which is detectable by the CCD response is shown in table 4.

TABLE 4. PERCENTAGE OF LIGHT PASSED BY FILTERS WHICH IS DETECTABLE BY CCD.

Filter Set	Red	Yellow	Green	Blue
Dichroic Three Color	50%	-	100%	90%
Artificial Three Color	100%	-	100%	95%
Bandpass Four Color	100%	100%	100%	90%

6. Specification sheet CCD 131, Fairchild Semiconductor, Mountain View, March 1976, Pg. 3.

Recall that table 4 does not present the quantity of light that is available, but merely the percentage of the light which falls within the spectral response of the CCD. The quantity of light available for detection would be most for the artificial three color set, and least for the bandpass four color set. Let us calculate the amount of light that is detectable by the CCD by including all the system components.

The monochromatic TNT is designed with 17 1,000 watt lamps illuminating the 122x183 cm model board. We estimate that 50 percent of this light is lost; therefore, we have available 8,500 watts, or 0.38 W/cm^2 at the model board. Combining this quantity of light with the filter transmission data from section IV, and the CCD response from table 4, we find the irradiance for the dichroic filter set to be,

$$E_{PR} = E_m \, T_f \, S_{CCD}$$

$$= (0.38 \, \frac{W}{cm^2})(.22)(.5)$$

$$= 42 \, \frac{mW}{cm^2} \quad \text{(red)}$$

and similiarly for green,

$$E_{PG} = (0.38 \; W/cm)(.08)(1)$$

$$= 34 \; mW/cm^2 \quad \text{(green)}$$

and blue,

$$E_{PB} = (0.38 \; W/cm^2)(.06)(.9)$$

$$= 21 \; mW/cm^2 \quad \text{(blue)}$$

We repeat this same calculation for the other two filter sets and arrive at the irradiance available in each color of each filter set at the probe entrance pupil. See table 5.

TABLE 5. IRRADIANCE AVAILABLE AT PROBE ENTRANCE PUPIL

Filter Set	Red	Yellow	Green	Blue
Dichroic Three Color	42 $\frac{mW}{cm^2}$	-	34 $\frac{mW}{cm^2}$	21 $\frac{mW}{cm^2}$
Artificial Three Color	46	-	46	43
Bandpass Four Color	15	15	27	14

The total signal activating the CCD is thus 97 mW/cm^2 for the dichroic set, 135 mW/cm^2 for the artificial color set, and 71 W/cm^2 for the bandpass filter set.

Now to determine the irradiance available for activating the CCD's, we calculate

$$E_{CCD} = \frac{\pi \ T \ E_p}{4 \ (f/no)^2}$$

where T = .3 is the probe throughput.

$$E_{CCD} = \frac{(\pi)(.3)(42 \ mW/cm^2)}{4 \ (16)^2}$$

$$= 39 \quad \mu W/cm^2$$

Multiplying by the integration time of 26 μs we find the exposure,

$$E = t_{INT} \ E_{CCD}$$

$$= (26 \ \mu S)(39 \ \mu W/cm^2)$$

$$= 1.01 \times 10^{-3} \quad \mu J/cm^2$$

Thus yielding a maximum CCD output signal of,

$$V = RE$$

$$= (2.6 \ V/ \ \mu J/cm^2)(1.01 \times 10^{-3} \ \mu J/cm^2)$$

$$= 2.6 \ mV$$

The peak-to-peak noise of the CCD at 26 μS integration time is,

$$N = (2.0 \ mV)\left(\frac{26 \ \mu S}{768 \ \mu S}\right) = 0.068 \ mV.$$

Therefore the signal-to-noise ratio is,

$$SNR = \frac{2.6 \ mV}{0.068 mV} = 38$$

Repeating the above procedure for the other color bands and other filter sets we arrive at table 6.

TABLE 6. CCD SIGNAL TO NOISE RATIOS

Filter Set	Red	Yellow	Green	Blue
Dichroic Three Color	38	-	18	7
Artificial Three Color	42	-	37	15
Bandpass Four Color	14	11	23	5

We see from table 6 that none of the schemes provide a SNR of 100 as required[7]. Therefore the CCD units must be cooled unless other measures are taken to increase the amount of signal from the CCD. If the color temperature of the lamps is shifted more toward 6000° Kelvin, then possibly a factor of two could multiply each SNR shown in table 6. Lowering the f number of the system to 10 would yield a factor of 4 times SNR.

7. OP. CIT., J. R. Cavanaugh, Pg. 832 ff.

SECTION VI

FLICKER

For the TNT monochromatic model a frame rate of 30 Hz and a field rate of 60 Hz were chosen to avoid flicker. This is consistent with black and white television rates and will probably be satisfactory because the luminance will not vary greatly from frame to frame. In a multicolor display model however, one must realize that the amount of any one color in any single location will vary greatly from frame to frame. Thus, a higher field rate will be necessary to avoid flicker. We define a "field" as the 30° sector projected by one laser beam before any interlacing. Let us call it sector sequential color.

Multicolor television, having a 100 foot-lambert highlight luminance, requires at least a 144 Hz[8] field rate to produce a flicker free image. The required field rate decreases with luminance of the display; so in this system, having a 10 foot-lambert luminance, it is expected that the 120 Hz field rate chosen by the Project Engineer (30° sector rate) will suffice so long as we use one-third of the lasers for each color.

If we choose to use four colors, the field rate for each color will be 120/4 = 30Hz, and will probably have color flicker. Most likely the field rate would have to be increased to 150 Hz or 180 Hz to eliminate perceptible flicker. In the 5-3-4 laser combination described above, the 3 green lasers may be separated far enough in time to produce flicker when the field rate is 120 Hz. And since green will be the predominate color in the expected scenes, one may want to avoid the 5-3-4 combination in order to avoid having to increase the field rate.

The absence of phosphors on the screen will probably not affect the flicker of the picture in any way. In television it is required that the phosphor decay to a low level in the time it takes to scan one picture element[9]. It's chief purpose is to convert the electron beam into visible light at the TV face-plate and not to affect flicker in any way[10]. It may be possible to use specially chosen phosphors for coating the screen surface to increase the light level of the display. The lasers would then be painting the phosphors which in turn create the image. We must recall that infrared lasers are to be avoided because of the lens design (see Section II).

8. D. G. Fink, Television Engineering, McGraw Hill, New York, 1952, Page 490.
9. IBID., D. G. Fink, Page 92.
10. A. M. Morrell, et. al., Color Television Picture Tubes, Academic Press, New York, 1974, Page 6.

SECTION VII

LASER SPECKLE

The quantity and granularity of the laser speckle in a multicolor TNT should be exactly the same as when using one color because in both cases we are using 12 separate lasers against the same screen surface. The speckle will however now be in three (or four) different colors. If the laser speckle noticeably moves in the single color model, it may move in three (or four) slightly different manners in the multicolor system because of the difference in the refraction of the observers eye at the various wavelengths[11]. It is anticipated that the laser speckle in a multicolor TNT model will offer no greater problem than is found to exist in a single color model.

11. Neil Mohon and Al Rodemann, "Laser Speckle for Determining Ametropia and Accomodation Response of the Eye," Applied Optics, Vol. 12, April 1973, Pg. 783.

SECTION VIII

CONCLUSION

The conversion of the single color TNT to a multicolor system is not a simple task, and will require a significant amount of design and planning. However, none of the tasks appear insurmountable, nor do they require any technological breakthroughs.

No problem is foreseen in the lens design or laser speckle portion of the system. It appears that the most satisfactory approach to the laser light proportions in the projector subsystem is the red, green, blue 4-4-4 combination operating at a field rate of 120 Hertz to avoid color flicker. The most difficult task, as I see the problems at this moment, is the efficient matching of the CCD spectral response to the model board lamp output with the possible use of artificial model board colors and CCD cooling. The signal-to-noise ratio must be given careful attention throughout the design.

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7. Op. Cit., J. R. Cavanaugh, Pg. 832ff.

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